PERIODIC MODULATION OF THE ATMOSPHERE OF ALPHA ORIONIS

A. K. Dupree[1], S. L. Baliunas[1], E. F. Guinan[2], L. Hartmann[1], G. E. Nassiopoulos[1], and G. Sonneborn[3]

[1]Harvard-Smithsonian Center for Astrophysics,
[2]Department of Astronomy, Villanova University,
[3]Astronomy Programs/CSC and *IUE Observatory*, Goddard Space Flight Center

ABSTRACT

Alpha Orionis (Betelgeuse; M2 Iab) has been monitored with *IUE* since 1984. Discovery of a 420-day periodic modulation of the flux in the optical and ultraviolet continua, and in the Mg II *h* and *k* line emission cores suggested that periodic photospheric pulsations were present from 1984-1986 (Ref. 1). This behavior continues through 1987. However, the general flux level of the ultraviolet continuum and the Mg II lines is decreasing, and the amplitude of the variation may be reduced. These decreases may be the emerging signature of an additional longer period. The density sensitive C II diagnostic, λ2325.4/λ2328.1, indicates the chromospheric densities range between log N_e (cm^{-3}) = 8.7 and 9.5, but periodicities are not yet evident.

Keywords Chromospheres, Mass Loss, Pulsation, Supergiants, Star: Alpha Ori.

1. INTRODUCTION

Because of the long life of the *IUE*, it has been possible to discover significant astrophysical phenomena that might otherwise have remained undetected. Alpha Orionis (Betelgeuse), a red supergiant star classified as M2 Iab, has been monitored intensively since 1984 with *IUE*. The 420-day modulation discovered (Ref. 1) in Alpha Ori's ultraviolet (λ3000) continuum, the Mg II *h* and line emission cores, and the optical (λ4530) continuum during 1984-1986 appears to result from radial pulsation that can heat and extend the atmosphere of this low gravity star, and perhaps initiate the mass flow.

The mechanisms of mass loss for luminous stars remains a perplexing problem in astrophysics, and the discovery of pulsations in Alpha Ori and other stellar populations (see, for instance, Ref. 2) may provide the important clues to the physics of driving a stellar wind.

Recent high precision measurements of the photospheric radial velocity of Alpha Ori during the 1984-1987 seasons show (Ref. 3) a periodicity of 420 ± 20 days which is anti-correlated with the ultraviolet continuum variations, as is true for many other radial pulsators. The pulsation semi-amplitude has values between 1 and 2 km s^{-1} which are in harmony with the predictions made (Ref. 1) based on the light curves of other pulsators and theoretical calculations. The amplitude of the light variations decreased from 1984 through 1986 (Ref. 1), and the photospheric velocity variations also were reduced through the 1987 observing season (Ref. 3). Establishment of pulsation in Alpha Ori marks an important milestone for stellar physics.

Observations of Alpha Ori with *IUE* have continued through 1987 and 1988. Happily, the program has been approved for two more years until the summer of 1990. This paper reports measurements through 1987, and initiates the search for signatures of periodic changes in the density of the atmosphere that might be expected to result from the pulsations modulating the optical and ultraviolet continua and the chromospheric lines.

2. THE ULTRAVIOLET CONTINUUM

Broad-band measurements of the continuum centered on λ3000 have been obtained from large aperture exposures with the LWP camera. These observations show a systematic decrease in the level of the ultraviolet continuum on which periodic variations are superposed (Fig. 1). The long term variation may be the appearance of a long term modulation similar to the 5.78 year light and velocity variations that were suggested by spectroscopists more than half a century ago (Ref. 4, 5).

The linear dependence of the flux has been removed (top panel of Fig. 3). The amplitude of the variation may be decreasing, but seasonal gaps in the data due to the observing constraints of the *IUE* make definite identification difficult. Inspection of Figure 1 shows that the *minimum* values of the ultraviolet continuum which are observed, have remained fairly constant; the times when maximum might be expected (1986.5 and 1987.5, for instance) have not been accessible due to Sun constraints. Power spectrum analysis of the flux (see Fig. 3) reveals a period of 1.12±0.02 years for the years 1984.0 - 1988.5. This value is slightly less than the period of 1.21±0.03 years found from analysis of the continuum observations 1984.0 - 1986.0, but in better agreement with the Mg II and "B" magnitude periods at that time (Ref. 1).

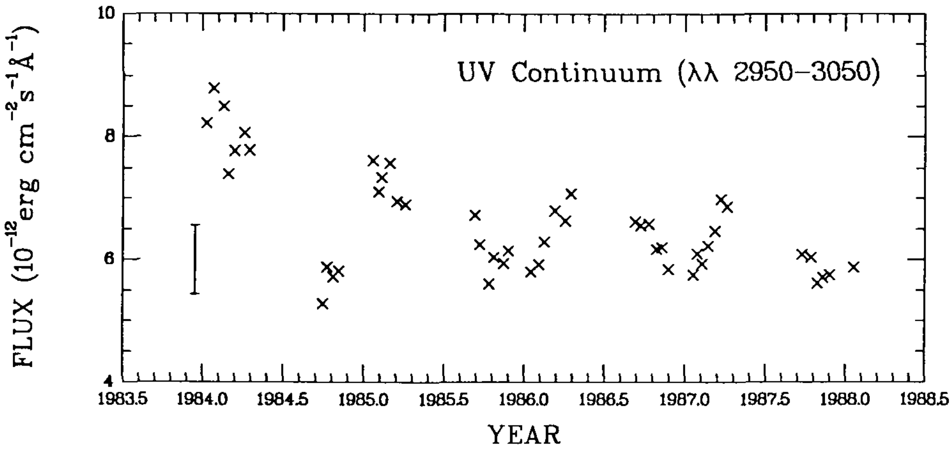

Fig. 1· The ultraviolet continuum of Alpha Ori in the wavelength interval λλ 2950-3050 during the period 1984.0 - 1988.05. The amplitude of the variation is much above the ≈6 percent uncertainty to be expected from broad-band *IUE* measurements, as indicated by the error bar.

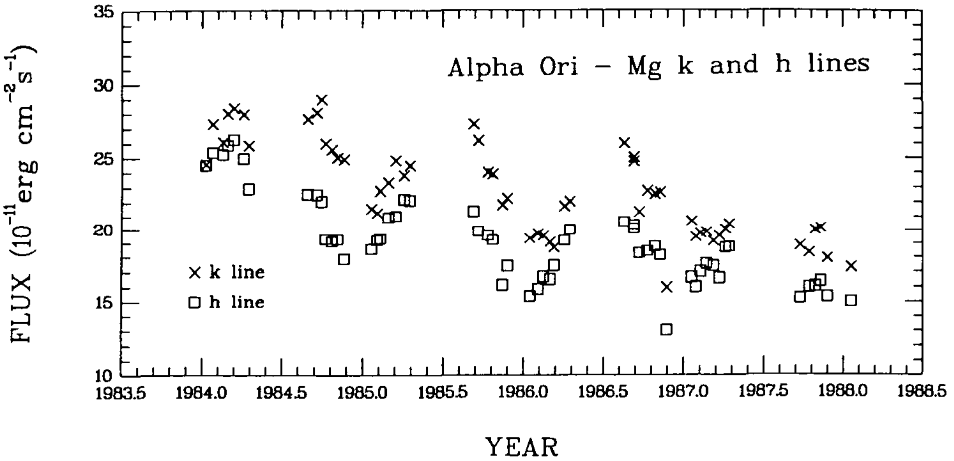

Fig 2. Fluxes in the Mg II *h* (λ2802) and *k* (λ2795) emission cores of Alpha Ori.

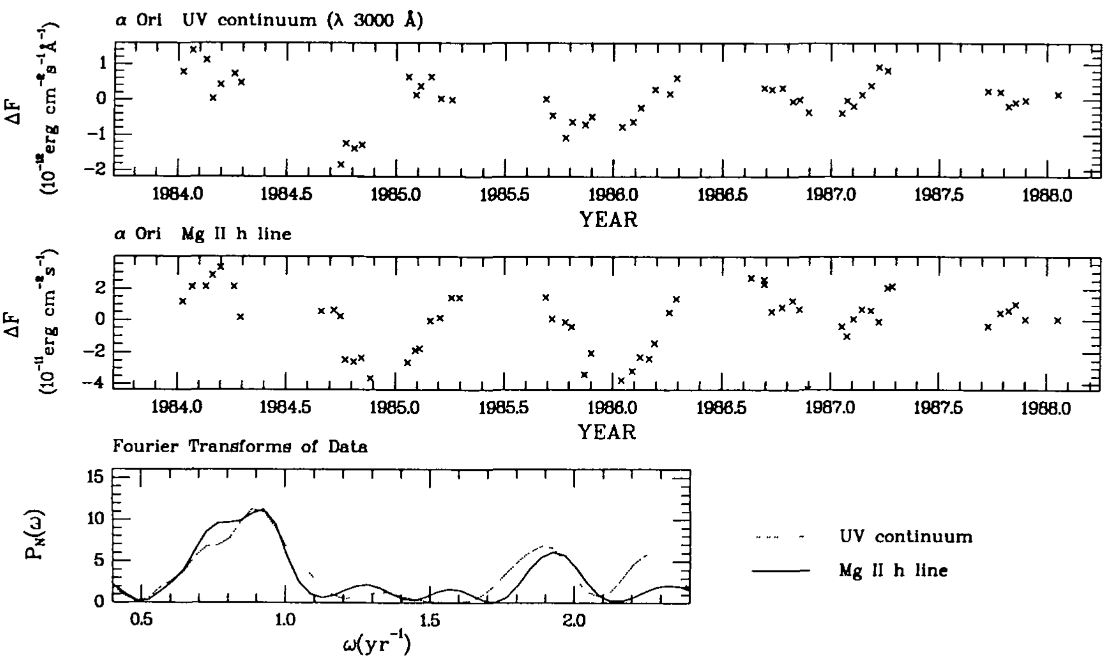

Fig 3: Observations of Alpha Ori 1984.0 - 1988.05 with linear dependence removed (*top two panels*), and the power spectra (*bottom panel*) of the two quantities: UV continuum (λ3000) and the Mg II *h* line (λ2802).

3. THE MG II LINES

The flux in the emission cores of the Mg II *h* (λ2802) and *k* (λ2795) lines obtained from high resolution spectra taken with the LWP camera through the large aperture are shown in Fig. 2. As noted earlier, (Ref. 1), the lines do not vary in similar fashion, perhaps due to circumstellar or interstellar contamination, or atmospheric motions, or changing wind opacity. Because the *h* line appears to follow the variations of the ultraviolet continuum better than the *k* transition, we use the *h* line for period analysis (see Fig. 3). The period derived corresponds to 1.09 ± 0.02 years which agrees with our earlier results (Ref. 1), and the ultraviolet continuum measures discussed above.

4. THE C II LINES

The moderately strong C II transitions near λ2335 were recognized (Ref. 6) to offer a useful density diagnostic for the atmospheres of luminous cool stars, and long (≈45 min) high resolution exposures with the LWP camera through the large aperture have been obtained in order to measure the relative line strengths.

In Alpha Ori, however, and most probably other cool supergiants as well, the appearance of a variable Fe II emission feature (see Fig. 4, and also Ref. 7) severely compromises the use of two out of three identified (Ref. 6) line ratios to be used as diagnostics.

Carpenter (Ref. 7) noted, from comparison of the Alpha Ori spectrum to that of a giant star (Ref. 8), that the Fe II lines are likely to be centrally reversed in Alpha Ori. An Fe II line (λ 2327.391; Mult. 3) lies close to C II (λ2328.133); whereas the long-wavelength component of the Fe II line is obvious in the spectrum (Fig. 4), and can be easily separated from C II by Gaussian deconvolution, the short wavelength component is not visible because it is blended with the C II transition at λ2326.930. Moreover, the ratio of the fluxes in the short and long wavelength components of Fe II varies as measured in numerous spectra which are sufficiently well exposed to reveal another component of the same multiplet (λ 2338.005). Thus if removal of the short wavelength component of the offending Fe II line were attempted, an uncertainty of as much as ±30 percent exists in its value. Unfortunately also, the Fe II line can itself represent a fair fraction of the C II line - values of one-third are not uncommon, so that the density-sensitive ratio can easily have errors of fifty percent. These uncertainties are unacceptable, and so we have not used all three ratios, but only the one formed from λ2325.4/λ2328.1. The λ2325.4 line is the strongest of the multiplet, making its measurement the most reliable.

The fluxes in the lines were extracted by simultaneously fitting both the continuum and Gaussian line profile using least-square techniques. Eleven high-dispersion, large aperture spectra, acquired between 1984.02 and 1988.106, were sufficiently well exposed to be useful. The ratio, R_1, is shown in Fig. 5 as a function of the relative flux in λ2325.4. The values of the ratio correspond to electron densities varying from log N_e = 8.7 to 9.5 cm^{-3} (R_1 = 3.8 and 2.4, respectively), according to the calculations in Ref. 9. The value of the ratio tends to be higher in Alpha Ori (and thus the inferred density is less) than the values derived (Ref. 10) for giant stars, α Boo, α Tau, and β Gru.

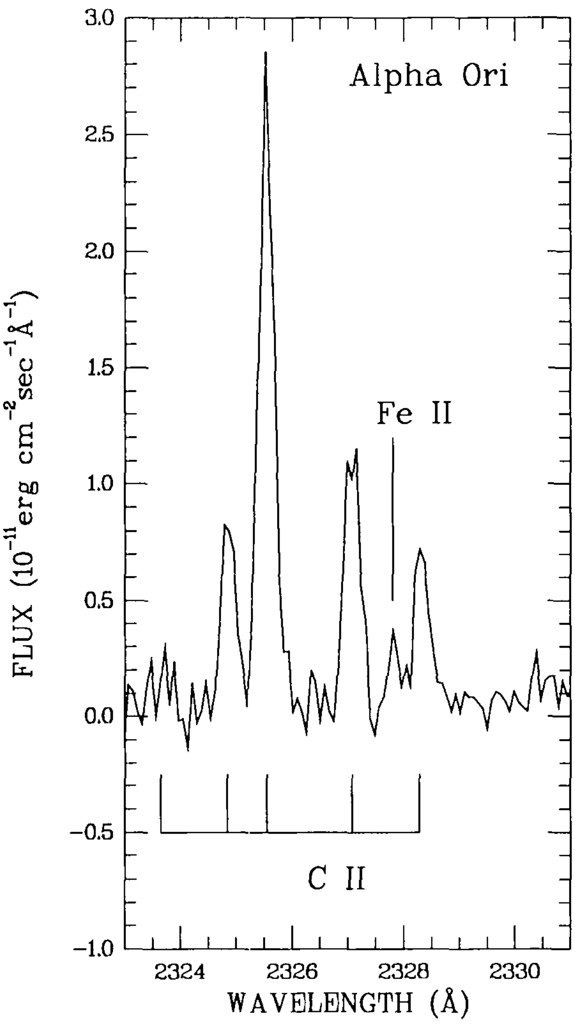

Fig 4 Emission lines from the density-sensitive C II multiplet near λ2325 in LWP 12517 (17 Jan. 1988). The weak feature of Fe II (λ2327.4, Multiplet 3) appearing shortward of λ2328 is double-peaked in Alpha Ori spectra. The long wavelength component is visible (marked as Fe II) and clearly separable from the C II line (λ2328.1) but the short wavelength component blends with the C II transition of λ2326.9. The calibration of the observed flux was made with an arbitrary factor of 100 between the high and low dispersion sensitivity.

A variation in electron density of about a factor of 6 is not an unexpected value from density compressions and shocks resulting from pulsations of the photosphere. The data is not yet adequate to identify a period in the density variations.

5. CONCLUSIONS

Alpha Orionis continues to provide an excellent target with which to define the physics of chromospheres and stellar winds. The existence of several periods of variability in the emissions from the star is apparent, but not yet well-defined. It may be possible to extract variations of the atmosphere in response to photospheric pulsations. These are only hinted at in the present data. With observations during the next few

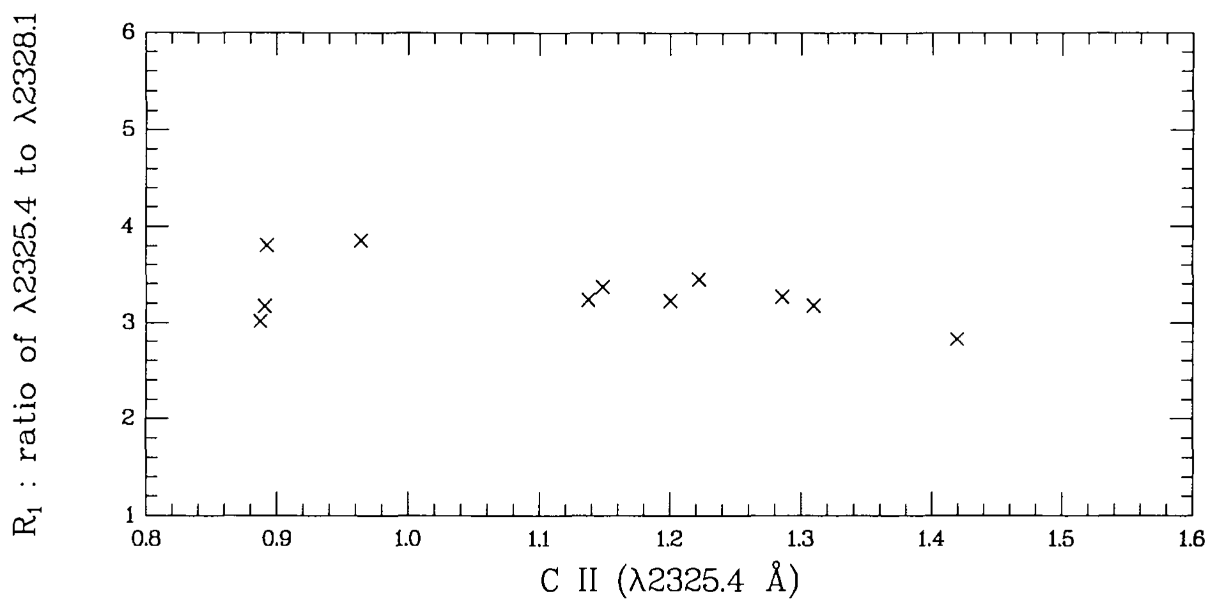

Fig 5· The ratio (R_1) of the C II lines λ2325.4/λ2328.1 as a function of the relative flux in the C II transition λ2325.4.

years, we should be able to pin down the existence of a long term period and associated chromospheric enhancements. By also acquiring quality observations of features unique to the ultraviolet, we can also make quantitative measures of the electron density and the motions in the star's atmosphere.

6. REFERENCES

1. Dupree, A. K., Baliunas, S. L., Guinan, E. F., Hartmann, L., Nassiopoulos, G. E., and Sonneborn, G. 1987, *Ap J*, **317**, L85.
2. Smith, G., and Dupree, A. K. 1988, *A J*, *in press (May)*.
3. Patten, R. M., Smith, M. A., and Goldberg, L. 1987, *Bull. Am Astron Soc*, **19**, 1028.
4. Sanford, R. F. 1933, *Ap J*, **77**, 110.
5. Stebbins, J. 1931, *Pub of the Washburn Obs of Univ of Wisconsin*, **15**, 177.
6. Stencel, R. E., Linsky, J. L., Brown, A., Jordan, C., Carpenter, K. G., Wing, R. F., Czyzak, S. 1981, *M N R A S*, **196**, 47p.
7. Carpenter, K. G. 1984, *Ap J*, **285**, 181.
8. Wing, R. F., Carpenter, K. G., and Wahlgren, G. W. 1983, *Perkins Obs Spec Pub*, No. 1.
9. Lennon, D. J., Dufton, P. L., Hibbert, A., and Kingston, A. E. 1985, *Ap. J*, **294**, 200.
10. Judge, P. G. 1986, *M N R A S*, **221**, 119.